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Volumetric behaviour of six ionic liquids from $T = (278 \text{ to } 398)$ K and up to 120 MPa

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ABSTRACT

In this paper the volumetric behaviour of the ionic liquids 1-butyl-1-methylpyrrolidinium tetracyanoborate, 1-butyl-1-methylpyrrolidinium trifluoromethanesulfonate, 1-butyl-1-methylpyrrolidinium tris(pentafluoroethyl)trifluorophosphate, 1,3-dimethylimidazolium dimethylphosphate, 1-ethyl-3-methylimidazolium hexylsulfate, and trihexyl(tetradecyl)phosphonium tris(pentafluoroethyl)trifluorophosphate is reported. Density was measured over the temperature range (278.15 to 398.15) K up to 120 MPa by means of a high pressure densimeter based on the vibrating tube principle. Experimental values were correlated as a function of temperature and pressure by means of the Tammann–Tait equation obtaining standard deviations lower than $3 \times 10^{-4}\ g \cdot cm^{-3}$. From this correlation, isothermal compressibility and isobaric thermal expansivity are obtained by differentiation. Furthermore, two group contribution methods proposed by Gardas and Coutinho and by Jacquemin *et al.* are applied to these fluids to analyse their prediction abilities to determine densities, as well as an equation proposed by Kiselev *et al.* to obtain isothermal compressibility at 0.1 MPa.

1. Introduction

One of the most important groups of industrial lubricants is hydraulic fluids, which have a market share of 15% in Europe and 22% in the USA [1,2]. Water had been initially used in hydraulic engineering but it presents limitations due to its poor lubricity and low boiling point [3–5]. Therefore, new kinds of hydraulic fluids were required in the first years of the 20th century. Refined mineral oil was employed mainly for warships to aim heavy artillery, whereas during the Second World War synthetic hydraulic fluids were developed for military purposes mainly in aviation [6,7]. Nowadays there are several types of synthetic hydraulic oils such as alkylbenzenes, polyglycols, polyphenyl ethers, polyalphaolefins, diesters and (polyol, phosphate or silicate) esters [8,9], but also the use of vegetable oils is increasing due to their biodegrability.

The selection of the best lubricant for an industrial application requires the knowledge of its physical and chemical properties. In particular, density and compressibility (or its reciprocal (bulk modulus)) play critical roles in the performance of machines with hydraulic systems as well as in the characterization of a lubricant [8]. A compressible fluid leads to sluggish operation, greater energy consumption, and build-up of heat. [7,10]. In hydraulic systems that operate at high pressure, fluids with low compressibility (high bulk modulus) are required to transmit power efficiently *i.e.* a fast response time, high pressure transmission velocity and low power loss [8,11]. A hydraulic fluid with high compressibility will require larger fluid volume and weight in the system, as well as an increment of the line sizes and actuator cross-sectional areas to compensate for the lower stiffness of the fluid [6]. Increasingly, hydraulic systems have become smaller and are required to operate at higher pressures. This has demanded the use of more thermally, oxidatively, and hydrolytically stable oils, particularly in those systems which use high- pressure rotary vane pumps to deliver fluid pressure and flow [12].

Some ionic liquids (ILs) could be hydraulic fluids with high performance [3,8,13–15] due to their low compressibility, non-flammability, low volatility, good thermal conductivity and

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